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Los Alamos Neutron Science Center

# Research Proposal for the use of Neutron Science Facilities

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**Proposal Number:** 20111507
**Submission Number:** S1513
**Date Received:** 03/02/11

**Program Advisory Subcommittee:** Materials Science
**Focus Area:**

**Flight Path/Instrument:** Target 2 / Blue Room
**Estimated Beam Time (days):** 5
**Days Recommended:** 0
**Dates Desired:** 06/22/2011 - 06/26/2011
**Impossible Dates:** 07/11/2011 - 08/05/2011

**TITLE**
High Power Mercury Spallation Target Cavitation Damage 2011

☐ Continuation of Proposal #:
☐ Ph.D Thesis for:


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| RESEARCH AREA | | FUNDING AGENCY |
|---|---|---|
| ☐ Biological and Life Science | ☐ Mat'l Science (incl Cond Matter) | ☐ DOE/BES |
| ☐ Chemistry | ☐ Medical Applications | ☐ DOE/OBER |
| ☐ National Security | ☐ Nuclear Physics | ☐ DOE/NNSA |
| ☐ Earth Sciences | ☐ Polymers | ☐ DOE/NE |
| ☐ Engineering | ☐ Physics (Excl Condensed Matter) | ☒ DOE/SC |
| ☐ Environmental Sciences | ☐ Instrument Development | ☐ DOE/Other |
| ☐ Nuc. Physics/chemistry | ☐ Neutron Physics | |
| ☐ Astrophysics | ☐ Fission | ☐ DOD |
| ☐ Few Body Physics | ☐ Reactions | ☐ NSF |
| ☐ Fund. Physics | ☐ Spectroscopy | ☐ Industry |
| ☐ Elec. Device Testing | ☒ Nuc. Accel. Reactor Eng. | ☐ NASA |
| ☐ Dosimetry/Med/Bio | ☐ Def. Science/Weapons Physics | ☐ NIH |
| ☐ Earth/Space Sciences | ☐ Radiography | ☐ Foreign: |
| ☒ Materials Properties/Test | ☐ Threat Reduction/Homeland Sec. | |
| ☒ Other: spallation targets | ☐ Other: | ☐ Other US Gov't: |
| | | ☐ Other: |

# PUBLICATIONS

**Publications:**

WNR Target 2 / Blue Room
1. B.W. Riemer et al. / Journal of Nuclear Materials 398 (2010) 207–219
2. N. J. Manzi, P. V. Chitnis, R.G. Holt, R.A. Roy, B. Riemer, and M. Wendel and R. O. Cleveland, "Detecting cavitation in mercury exposed to a high-energy pulsed proton beam," J. Acoust. Soc. Am. In Press (2010).
3. B. W. Riemer, et. al, "Results From Cavitation Damage Experiments With Mercury Spallation Targets At The LANSCE – WNR In 2008", Proc. 19th meeting on Collaboration of Advanced Neutron Sources (ICANS XIX), March 2010, Grindelwald, Switzerland, PSI-Proceedings 10-01 / ISSN-Nr. 1019-6447

**Abstract:** S1513_SNS-WNR_Test.pdf

By electronic submission, the Principal Investigator certifies that this information is correct to the best of their knowledge.

**Safety and Feasibility Review** ***(to be completed by LANSCE Instrument Scientist/Responsible)***

☐ **No further safety review required** ☐ **To be reviewed by Experiment Safety Committee**

☐ **Approved by Experiment Safety Committee, Date:**

| **Recommended # of days:** | **Change PAC Subcommittee and/or Focus Area to:** | **Change Instrument to:** |
|---|---|---|
| | | |

**Comments for PAC to consider:**

**Instrument scientist signature:** **Date:**

*Printed 4:41 PM, April 5, 2011*

# Test Plan for 2011 SNS Target Development Experiments at WNR

Proposal number: 2011-xxxx
Tracking number: S1513
Experiment title: High Power Mercury Spallation Target Cavitation Damage 2011
Flight path/data room: WNR Target 2 (Blue Room)
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## BACKGROUND / EXPERIMENT OVERVIEW

(Note: this experiment was approved and scheduled for December 2010. It was delayed by the SNS team due to difficulties in test preparations done at ORNL. The same experiment scope is envisaged for 2011).

For several years, the Spallation Neutron Source (SNS) target development team has been collaborating with the Weapons Neutron Research (WNR) group at the Los Alamos Neutron Science Center (LANSCE) to study issues associated with beam-induced cavitation in short pulse liquid metal spallation targets Although a WNR pulse contains less energy than a pulse for a 2 MW SNS, by focusing the WNR beam down to a size of about 20 mm diameter, the beam intensity (proton flux per pulse), and therefore local mercury pressure increase, expected for the SNS can be reasonably simulated.

Previous cavitation damage tests with mercury targets were performed in July and December of 2001 [1] June 2002 [1], June 2005 [4] and July 2008 [8, 9]. In the June 2005 experiments, a small flowing mercury loop (the In-Beam Bubble Test Loop, or IBBTL) was used to demonstrate that damage to the target container due to cavitation bubble collapse is reduced by flowing mercury (as opposed to stagnant), and a further reduction was obtained when gas bubbles were injected into the flowing mercury. These test conditions featured a 22 mm wide mercury channel with flow velocity limited to less than 0.5 m/s.

Small gas bubble injection tests did not achieve sufficient damage mitigation in the previous in-beam experiments. Creating the small bubbles in mercury is difficult as is evaluating the bubble populations. Progress has been made with off-line bubble generation and testing to the point that it is now time for another round of in-beam tests with the new bubbler options. Several candidate bubblers are under final evaluations for inclusion with the in-beam tests; all require a flowing mercury loop system.

A new test loop system for the proposed experiment is comprised of

1. An enclosure with the mercury pump, storage tank, heat exchanger and flow instruments
2. An enclosed test section consisting of cavitation test surfaces, bubble generators, a gas-liquid separator, and instrumentation including pressure, strain, gas flow and laser Doppler Vibrometers
3. Flexible, steel reinforced flexible hoses to complete the mercury circulation between pump and test sections
4. Chiller for providing cooled water to the heat exchanger

The new test loop system is named the Mercury Bubble Test Loop (MBTL). A photograph of the apparatus in early testing is shown in Fig. 1. Total mercury inventory is approximately 25 liters.

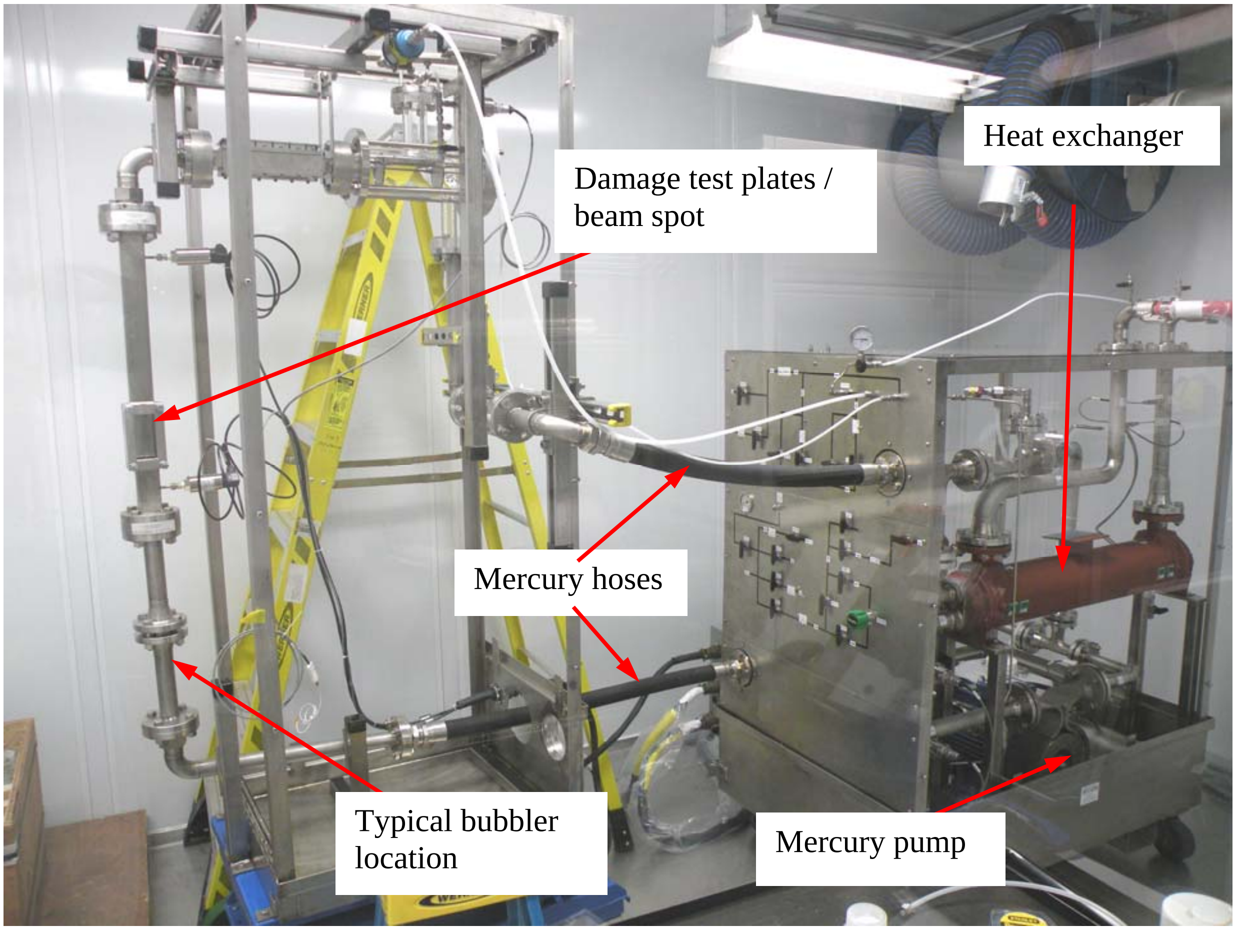


**Fig. 1** Photo of MBTL pump (right) and test (left) sections with enclosure panels removed

The incident beam will impinge on the vertical test section passing through 22 mm of mercury and two cavitation damage specimen plates (beam entrance and exit windows). Plates will be made of annealed type 316L stainless steel each about 1.5 mm thick in the beam path. Each test condition will require 100 pulses (beam specified below). Between test conditions the specimens will be exchanged by either individual replacement or by changing out an entire bubbler / test section vertical assembly. Choice will depend on the particular tests being conducted. Both options require hands-on work and efforts will be taken to minimize personal radiation exposure and contamination control. Key elements to accomplish this will be secondary containment around the test section; substantial ventilation of this containment (mercury and HEPA filtered); engineered connections and fasteners for quick and secure component replacement; local shielding for personal dose reduction; thorough testing and practice of adopted change-out techniques. Lessons learned from our 2008 WNR experiment will be applied.

Most of the bubbler options under consideration will be located in the vertical spool piece directly below the damage specimens / beam spot location. Some might require intermediate components between the pump and test sections; details are as yet not well defined.

Regardless, draining mercury to the storage tank is essential to any change-out work. Irradiated (and contaminated) test pieces will be moved to appropriate leak-tight containers as they are replaced. Based on past experiments a minimum waiting period of at least hour will pass before test condition changes.

The desired beam conditions as shown in Table 1 are expected to be steady between test conditions. Measurement of charge per pulse, beam centroid location and profile diagnostics will be essential elements of the experiment.

**Table 1** Desired WNR beam parameters

| | |
|---|---|
| Proton energy | 800 MeV |
| Pulse length | < 1 μsec |
| Protons per pulse | Ca. $2.7 \times 10^{13}$ |
| Sigma_X (half width) | 7 mm |
| Sigma_Y (half height) | 17 mm |
| Peak proton fluence / pulse | $3.65 \times 10^{10}$ protons/mm$^2$ |
| Equivalent SNS power | 2.5 MW |
| | |

The experiment has been designed to nominally circulate mercury at 1 liter/sec through the test section. The corresponding velocity at the damage test plates is 1 m/s. The pump is a permanent magnet induction pump designed and fabricated by the Institute of Physics University of Latvia (IPUL). SNS experiments have used similar pumps from IPUL with good experience. Pump curves for this pump are shown in Fig. 2.

 

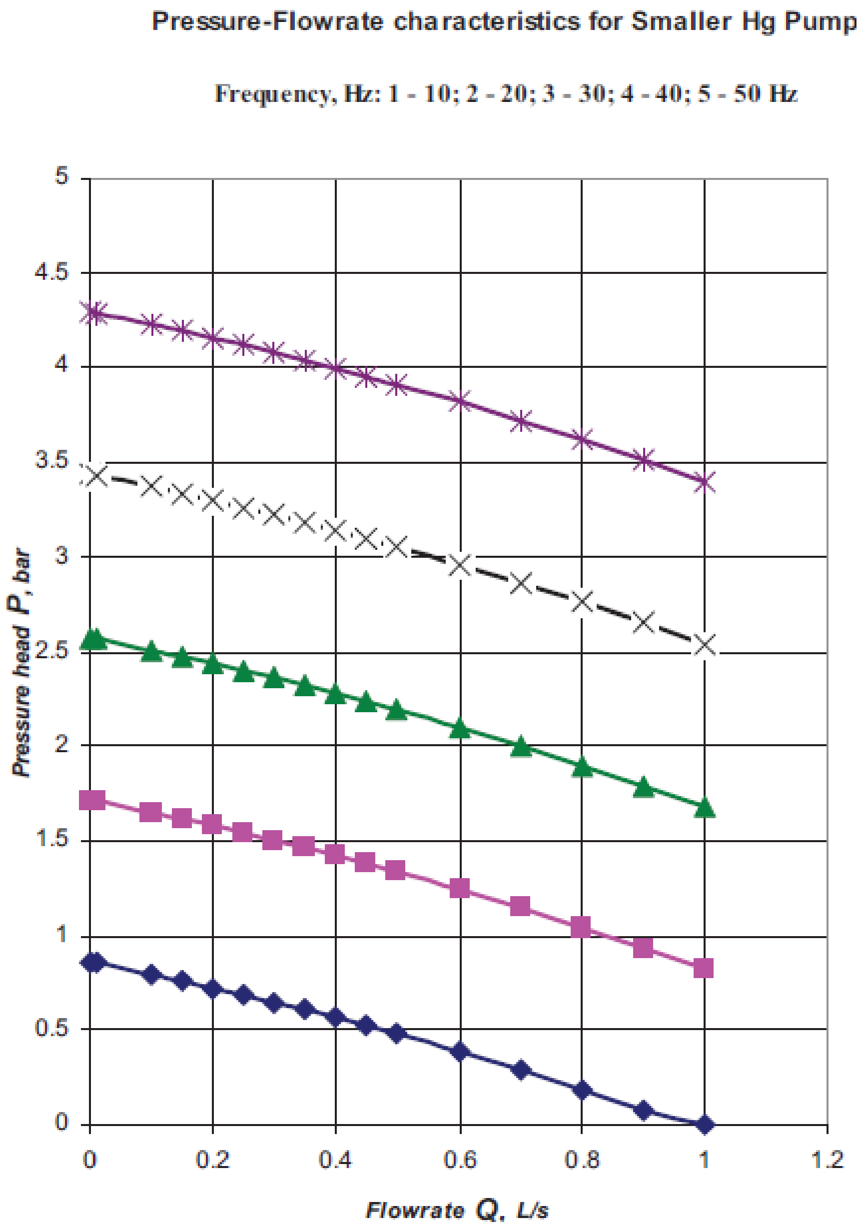


**Fig. 2** Pump curves for IPUL pump

The beam and magnetic pump will heat the mercury during the experiments. A heat exchanger and 10 kW chiller will be employed to control temperature (NESLAB Thermoflex 10000). Maximum temperature will be limited to 80°C at which point the control system will alarm to indicate operation should stop. Typical temperatures during experiments are expected to be below 60°C. The chiller will be situated in the Blue Room hallway and hoses will bring water to / from the beam area.

Bubblers require helium gas injection. Control of gas in the mercury is a key test issue and the test section incorporates a gas separator. Gas injection rate will be established by gas mass flow controller; vented gas flow will be measured by gas flow monitor. Control will be maintained on loop pressure. In addition calibrated pressure relief valve(s) will be employed to limit loop pressure to prevent damage to the loop. A flow system schematic is shown in Fig. 3.

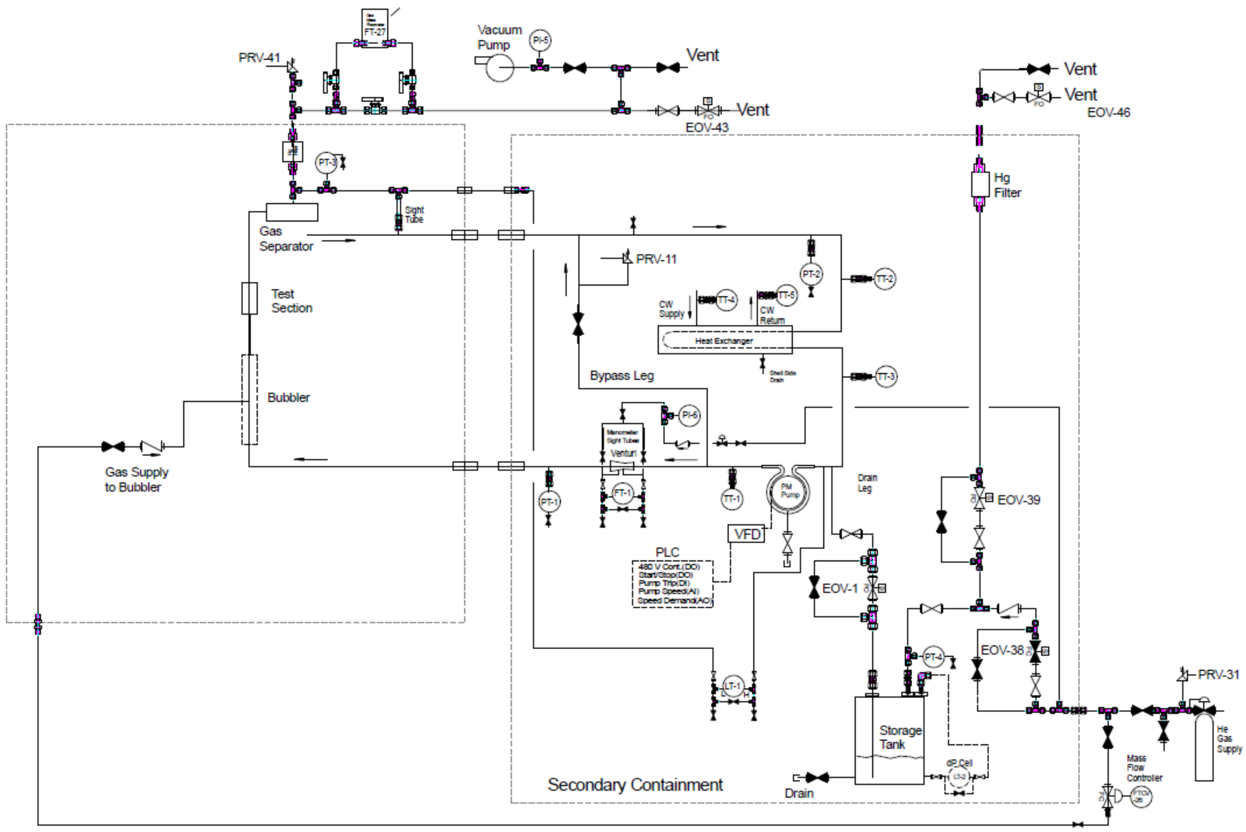


**Fig. 3** MBTL flow and instrumentation schematic

Currently six bubblers candidates are being considered for testing. Final selection will depend on testing at ORNL based produced bubble populations and uniqueness:

Bubble populations must have substantial void fraction comprised of bubbles of small diameters that theories suggest will be effective for pressure wave and damage mitigation. Diameter less than ca. 300 micro-m is of interest; hopefully some bubble populations will have diameters less than 50 micro-m. Secondly, little value is seen in testing multiple bubblers that produce similar populations. Secondary criteria will then be used make a selection from redundant performing bubblers. Furthermore, multiple bubble population conditions from a single bubbler are possible (for example, by adjusting mercury and / or gas rate). Control cases will also have to be performed: stagnant mercury without bubblers; flow without bubblers (two rates).

One additional test condition will be a gas wall mitigation test rather than small gas bubble mitigation. A special damage test specimen will be employed with gas injection directly at the specimen wall. No small gas bubble generator will be used. Otherwise the configuration will be the same as other test conditions.

The final selection of test conditions will not made until bubbler candidates are evaluated. We estimate the evaluations will be finished in April 2011. Nevertheless to accomplish these general objectives we request 5 days of beam time near the beginning of the 2011 run cycle. Each test condition will require 100 WNR pulses. Our expectation at this time is that about 1500 pulses (15 conditions) will be needed. Only 300 test pulses per day are believed reasonable - even with 24 hour operation – considering the activities and hazards associated with test change-out conditions.

General similarity to past mercury target experiments at the WNR is expected. There will a need for substantial setup time. A preparatory trip to LANSCE made in 2010 resolved many issues on logistics, setup, safety and waste. Immediately after our irradiation we expect to temporarily store activated apparatus and mercury in the Blue Room basement for a month or two. After that cool down period, team member will return to LANSCE to pack and ship the equipment back to ORNL. All mercury returns to ORNL. Some waste is expected to be generated at LANSCE. The support from and coordination with LANSCE waste services will be sought in advance.

New for this experiment, we propose use slightly activated mercury left from past WNR experiments from the onset. That mercury would be loaded into the MBTL prior to transport to LANSCE. We believe this will minimize ultimate disposition for our R&D program and incurs minimal additional risk. (Note: LANSCE agreed with this proposal for the 2010 experiment).

## MEASUREMENTS

The following measurements will be made:

(1) Material Damage: Pre-inspected damage test specimens are installed into each test target. After irradiation the targets will be drained and shipped back to ORNL where the physical damage will be assessed by microscopic examination;
(2) Laser Doppler Velocimetry (LDV) measurements: Two and possibly three LDV systems will be used to immediately assess cavitation potential from acoustic emissions associated with cavitation bubble collapse;
(3) Dynamic pressure measurements in the mercury near the beam spot;
(4) Dynamic strain measurements of the test section using fiber optic sensors;
(5) Beam charge per pulse using integrating current transformer; beam profile on target via capture of fluorescing plate in front of target (shape, location, maximum proton fluence per pulse);
(6) Acoustic passive cavitation detection;
(7) Sight-glasses on storage tank and loop weldment;
(8) Venturi flow meter on mercury loop;
(9) Activation foils placed directly on target's proton flight path to provide post experiment measure of integrated proton beam profile and intensity;
(10) Thermocouples mounted to the outside of each target and to the mercury loop (high alarm set-point of 80ºC).

Experiment hardware will be moved to be Blue Room basement for intermediate storage and activity decay after irradiations. Damage test plates, test sections and bubblers will be kept in secondary containers until they are to be prepared for transport back to ORNL.

All test target hardware and mercury will be returned to ORNL. A schedule for this will be determined in consultation with LANSCE.

Detailed step-by-step procedures has been drafted for operation of MBTL and anticipated experiment steps.

## SAFETY CONSIDERATIONS

Working with liquid mercury, particularly when irradiating the material, requires appropriate precautions and planning for safety. These proposed tests involve complications of flowing mercury and disconnecting mercury lines to replace test components. Lessons learned from our 2008 and prior target experiments will be applied.

The following precautions will be taken to ensure the protection of personnel and property during the experiments:

1) The ORNL staff will consult with ES&H staff from Los Alamos in the early stages of planning the experiments to ensure compliance with all WNR facility administrative and engineering controls and in keeping with the ALARA philosophy (mercury and radiation protection).
2) The secondary containers have liquid leak tight steel bottoms that can easily hold the entire mercury inventory of 25 L.
3) The floor under and around the targets and pump system in the Blue Room will be covered with suitable floor covering (OREX probable).
4) Throughout the concentration of mercury vapor will be monitored. Worker breathing zone vapor level must be below the ORNL safety limit of 0.025 $mg/m^3$, for working without respirators. (This is ¼ the OSHA long-term exposure limit). Normally at this action level work would stop and workers move back and assess the conditions and source of vapor. Given that mercury will be activated from the onset, all work with potential personal exposure to mercury vapor will be done with respirators with combo HEPA/mercury cartridges. The experiment team includes respirator qualified workers who can perform the anticipated operations and who can assist to contain a spill source if needed.
5) Appropriate personnel protective equipment (PPE) will be worn by personnel working with the mercury and entering the Blue Room. OREX has been recommended by LANSCE.
6) The secondary container for the MBTL mercury pumping system will be connected to a ventilation system which filters mercury vapor and particulate. Opening this container is not anticipated in the midst of the experiments. It is likely before and possible at the end of the experiment. The ventilation system will be activated whenever the secondary compartment is opened to minimize mercury vapor escape potential. The system ensures negative pressure inside the compartment.
7) Filtration of mercury vapor from the MBTL mercury pumping system exhaust will be ensured (this aspect of the operation has previously been implemented successfully numerous times. Similar filtration will be part of the mercury filling reservoir system used to fill rectangular targets.
8) Pressure relief valves are located in the loop to prevent damage to the primary pressure boundary.
9) A high temperature alarm in the MBTL control computer will be triggered if any one of the four measured temperatures exceeds 80°C.
10) Two (possibly three) class 2A laser will be used as part of a diagnostic system. Appropriate safety measures will be followed.

## TARGET DEPOSITION / ACTIVATION / DOSE RATE ESTIMATES

The basis of 2011 estimates is predicted and measured results (described below) from previous WNR experiments with *200* pulses per test conditions with the same typical charge per pulse as requested for the 2011 experiments. Those were for rectangular targets with stagnant mercury. Key differences exist which should result in less dose rate in the vicinity of the 2011 target test section for the same time after irradiation. Personnel dose for some individuals will be somewhat offset by longer time in the target vicinity to perform test section, bubbler and test plate configuration changes.

The 2011 test section is illustrated in Fig. 4 and the beam will be directed through damage test plates omitted in this view. The plates are 0.060” thick SS316L (1.5 mm). The mercury thickness between the plates is 0.880” (22.3 mm). The requested beam profile fits within upstream plate recess but MCNPX calculation estimating deposited energy indicate some spray in the downstream direction (Fig. 5).

The beam interaction length for the 2011 targets is substantially less than the rectangular targets typical of the dose estimation and measurement. Specific activation of the mercury should be lower in 2011 – even though total pulses (1500) will be on a single inventory of mercury – because the beam interaction volume is much lower and the total inventory is much higher (ca. 25 liter) than a single-use rectangular target (ca. 1.3 l). Mercury will be drained the storage tank in the pump cart prior to configuration changes before personnel will have to work nearby. Some test condition changes involve replacement of the entire test section and bubbler. Once these are removed and stored, the exposure around the apparatus will be reduced substantially. Cases where only damage plates are exchanged will leave the hot test section and mounting box in place, thus keeping these source contributors in the work area while new plates are installed.

Damage plate activation should be comparable to *half* the rectangular target estimates by virtue of 100 vs. 200 pulses per test condition. The graphite beam dump will be absorbing a substantial fraction of the proton pulse, so dose from it is expected to be high after an irradiation. Its movable lead shield will help mitigate this.

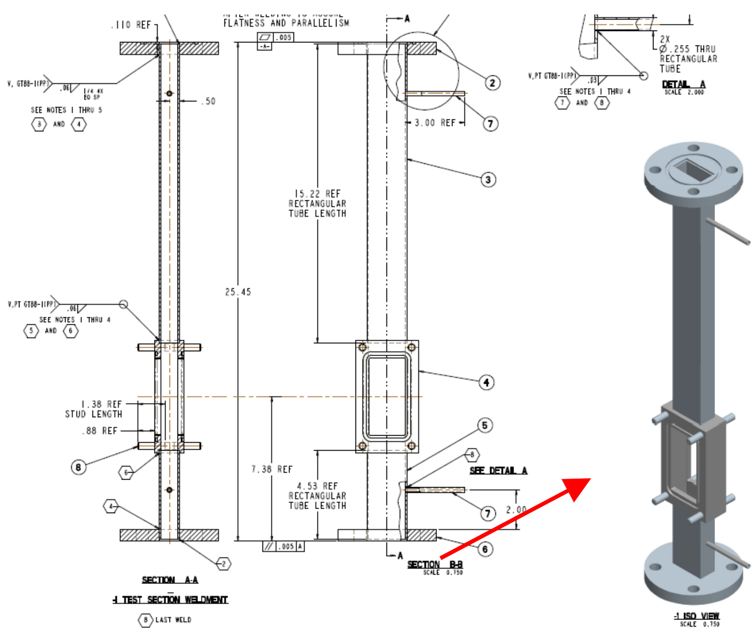


**Fig. 4 MBTL test section with damage plates omitted. Arrow indicates beam direction.**

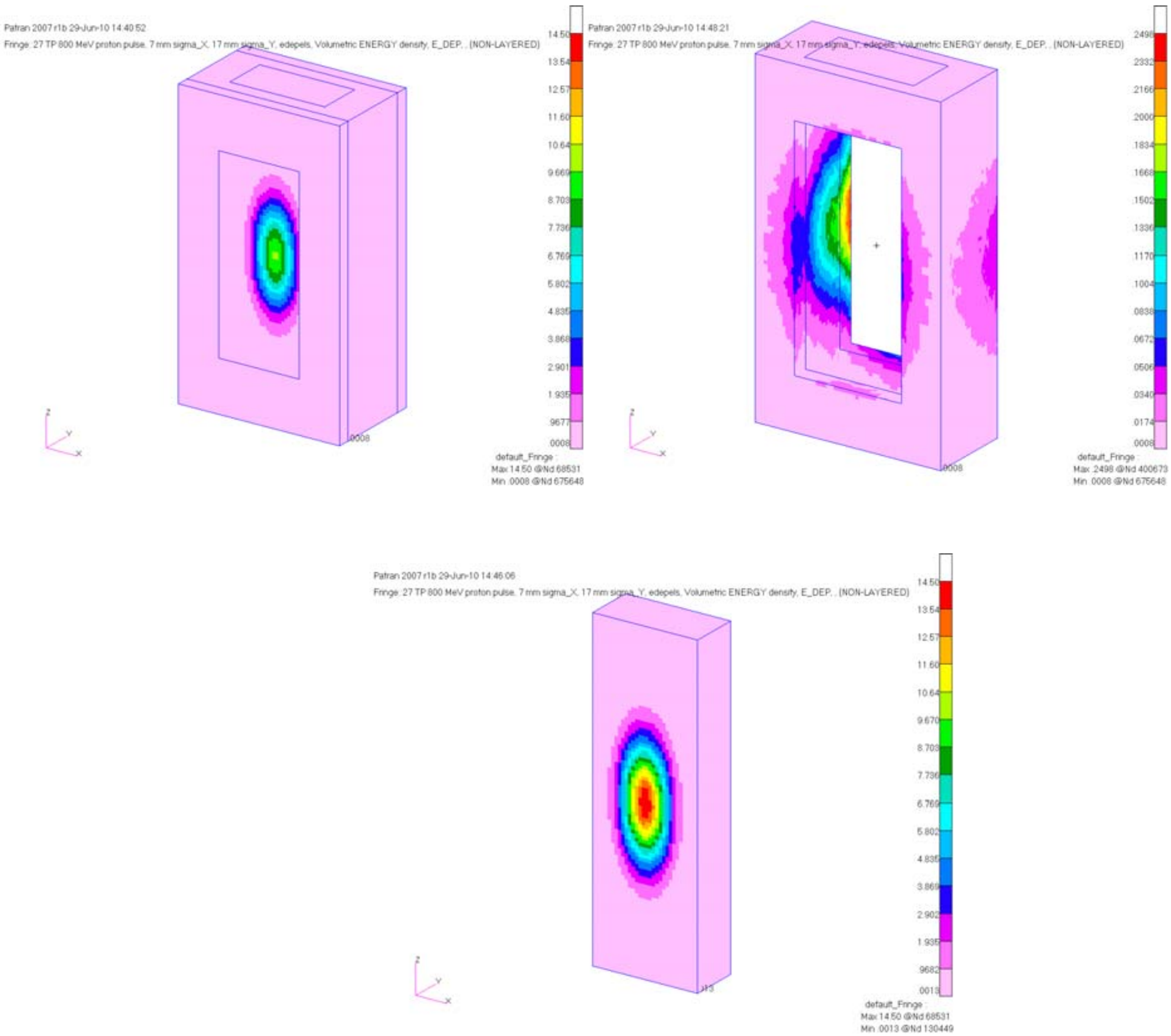

**Fig 5 MCNPX energy deposition estimates in the test plate section (J/cc/pulse). Top left: test plates, mercury and mounting box; top right: mounting box only; bottom: mercury**

**Rectangular Targets (previous WNR mercury target experience)**

Dose rates for the rectangular mercury-filled targets (Fig. 6) were previously estimated to determine the radiation environment that can be expected during the test period as well as in unloading the mercury after a wait of approximately one month after the tests.

Predicted and measured results from previous tests with *200* pulses with approximately 2.8 x $10^{13}$ protons per pulse showed remarkable agreement with measured data (Fig. 7). Recalculating the dose rates on the rectangular targets for 100 pulses with 30 seconds dwell time between pulses, the dose rate at shutdown is estimated to be 28 rem/h at the surface of the secondary container immediately after the $100^{th}$ pulse. Similar *or less* dose rate is expected from the MBTL targets: the mercury will have been drained to the system storage tank.

To minimize worker exposure, we plan to allow at least 1 hour of cool down after irradiating a target, which brings the dose rate to 1.0 rem/h at 0.3 m from the surface of the target.

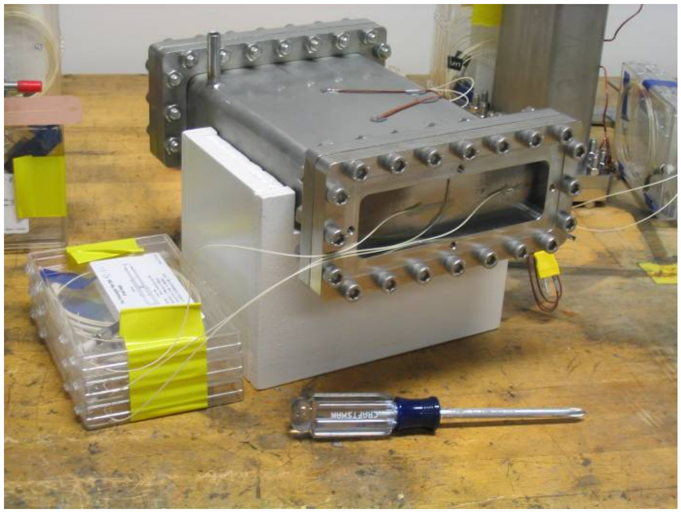

**Fig. 6 Example rectangular target typical for the dose estimation / measurement. Mercury length is 9 inches (228 mm). The mercury width and height are 5-5/8 x 1-5/8 inch (143 x 41 mm). Beam windows were 0.08" thick SS316L.**

**Personnel Exposures**

We suggest using the same exposure limits as was used in the 2008 WNR experiment (RWP 2008-039-01) as a starting point. These established an individual ALARA goal was 150 mrem, and the collective ALARA goal was 1000 mrem,.

Targets will be stored at LANL for at least one month before returning to empty the mercury from the targets, packaging the targets and mercury, and shipping back to ORNL. The dose rate on contact with the targets exposed to *100* pulses is expected to be about 4 mrem/h at this time (Fig. 8).

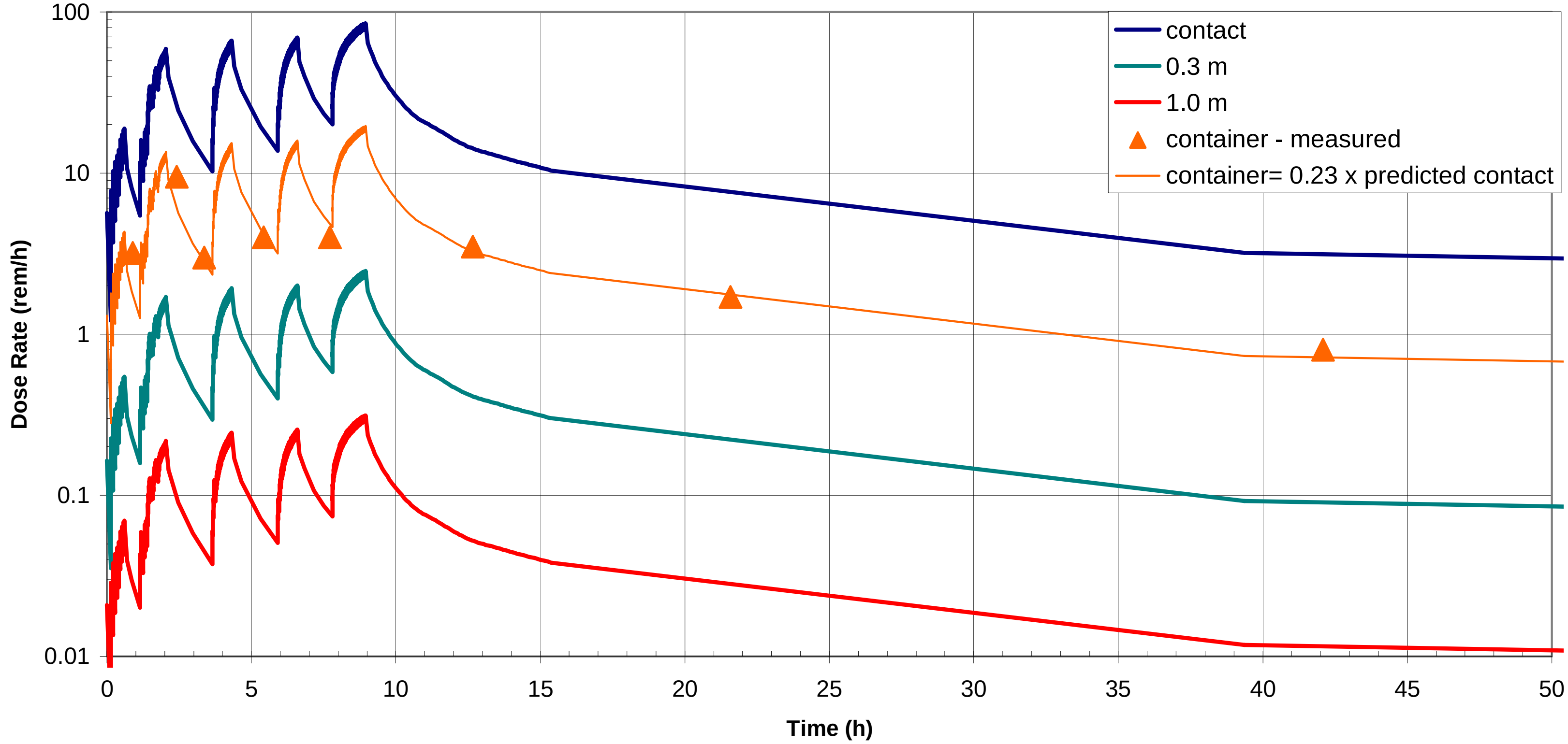


**Fig. 7. Target activation for *200* pulses from June 23-24, 2001 operations (5).**

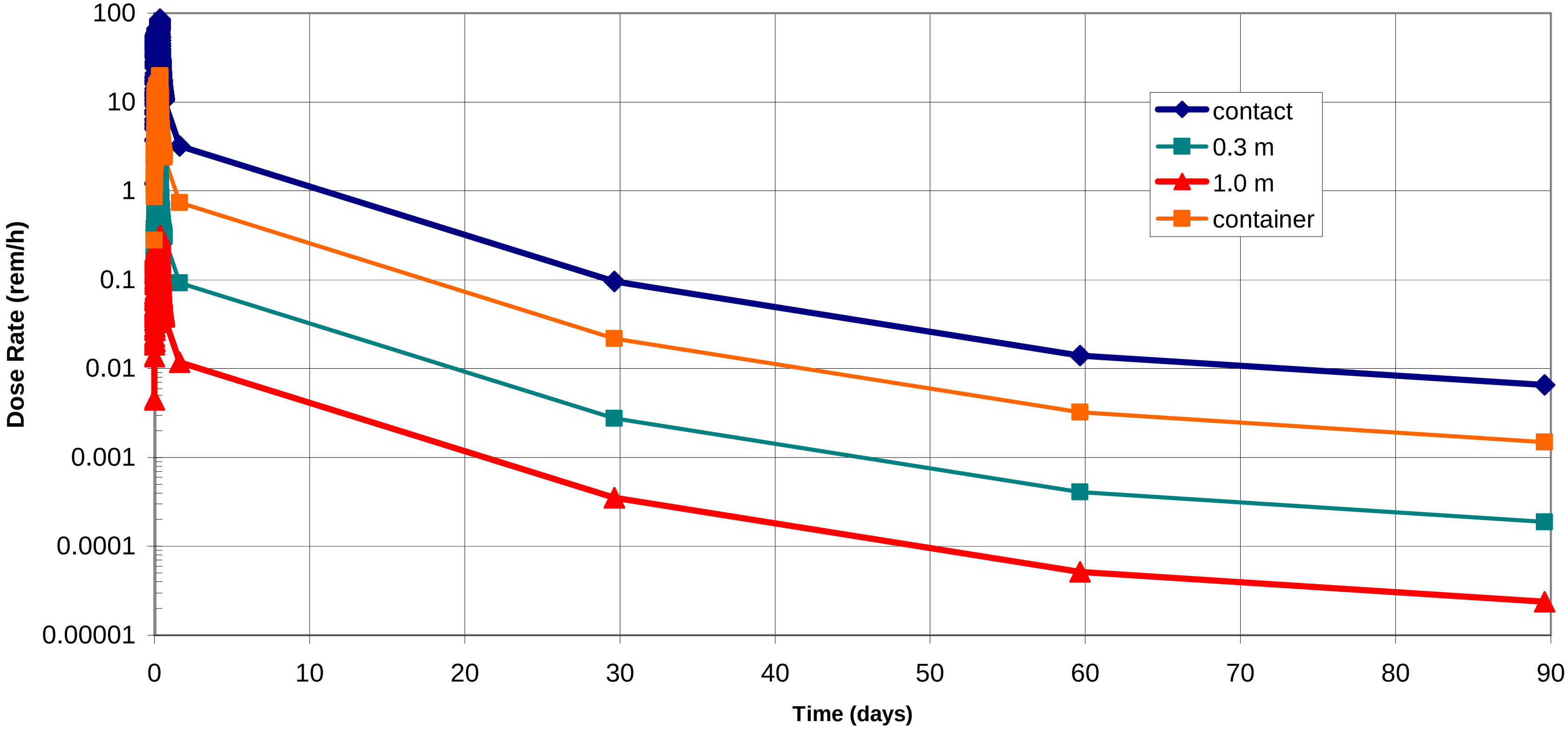


**Fig. 8 Target cooldown following *200* pulses.**

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The proposed personnel list is not final. Participants will be updated in advance of the assigned beam time.

**REFERENCES**

1. B.W. Riemer et al. / Journal of Nuclear Materials 398 (2010) 207–219
2. N. J. Manzi, P. V. Chitnis, R.G. Holt, R.A. Roy, B. Riemer, and M. Wendel and R. O. Cleveland, “Detecting cavitation in mercury exposed to a high-energy pulsed proton beam,” J. Acoust. Soc. Am. In Press (2010).
3. J. R. Haines, B.W. Riemer, D. K. Felde, J.D. Hunn, S.J. Pawel, Journal of Nuclear Materials, 343 (2005) 58-69.
4. B. Riemer, J. Haines, M. Wendel, G. Bauer, M. Futakawa, S. Hasegawa, and H. Kogawa, “Cavitation Damage Experiments for Mercury Spallation Targets at the LANSCE – WNR in 2005”, Proc. Spallation Materials Technology 8, submitted to the Journal of Nuclear Materials for publication.
5. J. R. Haines, B. W. Riemer, and C. C. Tsai, “Test Plan for December, 2001 Mercury Target Thermal Shock Tests,” submitted to LANSCE User Office December 11, 2001 Spallation Neutron Source Target Systems Report SNS/TSR-0219, SNS Project Report SNS-101050200-TR0010-R00.
6. J. R. Haines, B. W. Riemer, C. C. Tsai, and J. D. Hunn, “Test Plan for June, 2002 Mercury Target Thermal Shock Tests,” submitted to LANSCE User Office June 5, 2002 Spallation Neutron Source Report SNS-101060100-TR00005-R01.
7. J. R. Haines, B. W. Riemer, M. W. Wendel, “Test Plan for June 2005 SNS Target Development Experiments,” submitted to LANSCE User Office April, 2005 Spallation Neutron Source Report SNS-101060100-TD00001-R01
8. B. W. Riemer, M. W. Wendel, D. K. Felde, “Cavitation damage experiments for mercury spallation targets at the LANSCE – WNR in 2008”, Journal Nuclear Materials, 398 (2010) 207-219.
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# ATTACHMENT x

## High Mercury Vapor Response Procedures

Mercury vapor concentrations are to be monitored in the worker breathing zone during mercury handling activities using a Jerome meter. A safe working limit of 0.025 $mg/m^3$ has been established. Should this be exceeded, the following actions will be taken:

1. Workers move away from the area of high vapor concentration quickly. Reasonable time can be taken to leave equipment and mercury in conditions that minimize further vapor production.
2. After several minutes, the region will be approached with Jerome meter and breathing zone concentrations measured again. If concentrations are below 0.025 $mg/m^3$ work can continue.
3. If concentrations are still above 0.025 $mg/m^3$, workers will keep away for additional time. This sequence can be repeated a reasonable number of times.
4. If after repeated attempts to re-enter the work zone the breathing zone concentration does not fall to below the threshold, mercury absorbent respirators and PPE will be used. Workers will clean up and contain the mercury contributing to the high vapor levels while using respirators and appropriate PPE. Consult and get assistance from LANSCE IS.

## ATTACHMENT y

## Mercury Spill Emergency Response Procedures

In the event of a significant spill of liquid mercury, the following actions will be taken:

1. Workers leave the spill area of quickly.
2. Contact the EAM and CCR.
3. Anti-C suits and mercury absorbent respirators will be required for cleanup and containment work.
4. Mercury spill kit and other equipment / techniques will be used during clean up activities.